THE NICKEL BULLETIN

A SUMMARY OF CURRENT INFORMATION ON NICKEL

MARCH, 1953

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SPHEROIDAL GRAPHITE CAST IRON *page* 34

General

	Page
Atomic Theory for Students of Metallurgy	36
Equipment for Thermal Treatment of Metals and Alloys	36

Nickel

Solubility and Diffusion of Carbon in Nickel: Reaction of Nickel-Carbon Alloys with Barium Oxide	36
Anodic Behaviour of Nickel	36

Electrodeposition and Other Coating Methods

Testing of Electrodeposited Coatings	37

Non-Ferrous Alloys

A.S.T.M. Specifications for Nickel and Nickel Alloys	37
Monel Stays in British Standard Locomotives	37
Nickel-Aluminium Bronze: Properties and Uses	37
Nickel-Manganese Alloys	37
Nickel-Chromium-Palladium Alloys	37
Magnetic Characteristics of Nickel-Cobalt Alloys	38

Nickel-Iron Alloys

Permanent Magnets: Review of Development	38
Magnetostriction of Single Crystals of Nickel Ferrite	38

Cast Iron

Ni-Hard Equipment for Handling Sand and Gravel	38
Ni-Hard Service in the Brick-Making Industry	38
Current Developments in S.G. Iron	39

Constructional Steels

Thermal Stabilization of Austenite in Nickel-Alloy Steels	39
Influence of Boron Additions on Low-Alloy Nickel-containing Steels	40

Heat- and Corrosion-Resisting Alloys

Wear and Friction Properties of Nickel and High-Nickel Alloys	40
Oxidation of Metals and Alloys	42
The Nimonic Series of Alloys: Research and Development	42
Drilling Alloys of the Nimonic Series	42
Nickel-containing Materials in Naval Gas Turbines	43
Tests on Materials for Steam Superheaters	43
Resistance of Superheater Materials to Corrosion by Combustion Gases	44
Comparison of High-Alloy Welding Electrodes of Varying Nickel Content	45
Nickel-base High-Temperature Coating Alloy	45
Nickel-containing Materials for Use in High-Temperature Water Systems	46
Influence of Processing on Niobium-Stabilized Austenitic Steel	46
Accelerated Corrosion Test for Sheet Steel	46

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Table I

S.G. Iron

Properties as Cast and Annealed compared with those of High Duty Flake Graphite Cast Iron

Property		High Duty Flake Graphite Cast Iron	S.G. Iron	
			As Cast	Annealed
Maximum Stress	t.s.i.	18—22	35—45	27—35
	kg/mm²	28—35	55—71	47—55
Yield Point	t.s.i.	—	25—35	20—25
	kg/mm²	—	39—55	31—39
Elongation	per cent.	Nil	1—5	10—25
Transverse Rupture Stress	t.s.i.	38—42	55—65	55—60
	kg/mm²	60—66	87—102	87—94
Compressive Strength	t.s.i.	60—65	65—80	48—58
	kg/mm²	94—102	102—126	76—91
Compressive Yield Strength	t.s.i.	—	32—40	24—32
	kg/mm²	—	50—63	38—50
Elastic Modulus	millions of p.s.i.	18	25	25
	thousands of kg/mm²	13·2	17·6	17·6
Brinell Hardness		210—240	230—280	140—180
Impact Izod 10 mm. sq. Notched	ft. lb.	1	4	12
Impact Charpy 10 mm. sq. Unnotched	kg. m*	0·3	1·1	10
Endurance Limit Unnotched	t.s.i. ±	8·5	13—18	11—13
	kg/mm² ±	13·4	20—28	17·3—20
Endurance Limit Notched 0·05″ rad.	t.s.i. ±	8·0	9·5	8·2
	kg/mm² ±	12·6	15	13
Endurance Ratio Unnotched		0·43	0·34—0·38	0·37
Damping Capacity Ratio		4	2	1
Magnetic Initial Permeability	μ_o	250	75	—
Magnetic Maximum Permeability	μ max.	440	425	1400
Field Strength for μ max.		4·5	12	3
Saturation Induction		14,300	16,000	16,000
Steinmetz Factor	thousandths	5·6	5·6	1·9
Electrical Resistance	microhms/cm/cm²	75—106	55—65	50—55

* Kilogram-metres per cm² on 10×10 mm test pieces 40 mm span.

SPHEROIDAL GRAPHITE CAST IRON

BY changing the graphite in cast iron from the flake to the spheroidal form the strength of the iron is doubled and its toughness increased by from four to twelve times, thus largely eliminating the brittleness normally associated with iron castings.

These improved properties are secured by means of a patented process by which small proportions of magnesium are introduced into the iron, under specified conditions, and this process can be applied to all normal melting and casting practice. The two main types of S.G. iron are distinguished by their microstructures and are known as *pearlitic* and *ferritic* respectively. The pearlitic structure is normally obtained in the iron in the as-cast condition, and the ferritic structure is developed by a short heat treatment. It will be noted that this heat treatment lowers the *tensile strength* and hardness to some extent but increases the *elongation* and *impact* values.

The figures quoted on these pages will assist designers to assess the value of this new range of materials. The following points are of special interest.

The *stress/strain* curve is similar to that of steel and exhibits a distinct yield point. The *yield point* is high and is markedly superior to that of malleable cast iron; there is a measurable *elongation* with all types of S.G. iron, this rising to 20 per cent. or more in the ferritic grade. The *elastic modulus* is high and is independent of the matrix structure. The *shock resistance* is measurable by the methods employed for steel. The *damping capacity* is low compared with that of flake-graphite iron, as shown by the fact that the castings will emit a ringing tone when struck. S.G. iron *machines* readily and will take an excellent finish. *Welding* is effected by normal methods; *surface coatings*, whether by tinning, galvanizing or electrodeposition, are applied with ease. The *corrosion-resistance* of S.G. iron is, under most conditions, similar to that of flake-graphite iron, but its *heat-resistance* is superior.

The process for rendering the graphite spheroidal can be applied to irons alloyed to develop special matrix structures. Addition of nickel and molybdenum gives a high strength iron with an *acicular structure*. The *austenitic* S.G. irons provide castings which have excellent mechanical properties, are non-magnetic and are resistant to heat and corrosion.

Table II

Properties of Some Alloyed Irons

Matrix	Acicular		Austenitic	
Graphite Form	Flake	Spheroidal	Flake	Spheroidal
Maximum Stress .. .. .. t.s.i.	26—36	40—60	10—14	24—27
kg/mm²	41—57	63—94	16—22	38—43
Yield Point .. .. t.s.i.	—	30—40	—	15—16
kg/mm²	—	47—63	—	24—25
Elongation .. .. .. per cent.	Nil	Up to 5	1—2	10—20
Brinell Hardness	250 to 350		140 to 200	
Impact—Izod 10 mm □ Notched	—	4	4·5	12
Charpy 10 mm □ Unnotched ..	1	2	2	10

ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

Atomic Theory for Students of Metallurgy

W. HUME-ROTHERY: 'Atomic Theory for Students of Metallurgy.' *Inst. Metals, Monograph and Report Series No.* 3, Second (revised) edition, 1952; 331 pp. Price 21/-.

The first edition of this book has, since its publication in 1946, proved useful to advanced students of metallurgy wishing to appreciate the physical basis on which the fundamental theories of metals are being built. The advances which have been made, both in the underlying theory and in its application to metallurgy, have made necessary a revised edition, but radical changes have been avoided.

The author opens with a description of the basis of atomic structure, and of the elementary principles of wave mechanics, and after dealing with the electron distributions for free atoms, considers the various types of binding forces between assemblies of atoms, like and unlike. Up to this stage the main change from the first edition is in the revised electron distributions for the heavier elements, which are largely a consequence of the study of the transuranic elements. Thereafter the free electron theory and its application are dealt with, with special reference to the electrical and magnetic properties, and this leads on to the Brillouin-zone theory, insulators and semi-conductors. Finally, detailed consideration is given to the structures of different classes of metals and their alloys. The major changes from the first edition are in this part of the book, particularly in the chapters dealing with the elements of higher valency and with the transition elements. The value of the book has been considerably increased by additional references to recent work, and by the inclusion of a wider selection of suggestions for further reading.

Equipment for Thermal Treatment of Metals and Alloys

INST. METALS: 'Equipment for the Thermal Treatment of Non-Ferrous Metals and Alloys.' *Inst. Metals Monograph and Report Series* No. 14, 1953; 104 pp.

This publication contains the final forms of the papers presented at the Symposium organized by the Institute in March 1952, together with the discussion arising from them. For abstracts of papers, see *Nickel Bulletin*, 1952, vol. 25, No. 4, pp. 93-4.

Permanent Magnets: Review of Development and Current Position

See abstract on p. 38.

NICKEL

Solubility and Diffusion of Carbon in Nickel: Reaction of Nickel-Carbon Alloys with Barium Oxide

J. J. LANDER, H. E. KERN and A. L. BEACH: 'Solubility and Diffusion Coefficient of Carbon in Nickel: Reaction Rates of Nickel-Carbon Alloys with Barium Oxide.' *Jnl. Applied Physics*, 1952, vol. 23, Dec., pp. 1305-9.

Experimental values obtained by the authors for the solubility of carbon in nickel, in the range 700°-1300°C. yield the equation $\ln S = 2 \cdot 480 - 4{,}880/T$, where S is the solubility in grams of carbon per 100 grams of nickel. Values obtained for the diffusion coefficient in the same temperature range fit the equation $\ln D = 0 \cdot 909 - 20{,}200/T$, where D is in cm^2 per second. Attention is drawn to the interest of these results in connexion with the problem of activation of thermionic oxide-coated cathodes. The experimental method used to measure the diffusion coefficients was chosen to bear practical relation to phenomena occurring in vacuum tubes. Rates of diffusion were observed by measuring the reaction rates of diffused carbon with nickel-oxide coatings, the reaction rates being obtained by measuring the rates of evolution of the reaction products carbon monoxide and carbon dioxide. The results clearly illustrate a type of phenomenon to be expected in operation of tubes, and, in order to carry the analogy further, and to secure data of fundamental interest, rates of reaction of diffused carbon with barium oxide were also measured. The method appears to be potentially more sensitive than some other (standard) techniques.

The results showed the rates of reaction to be diffusion-limited over a wide range of conditions which are of practical interest.

A.S.T.M. Specifications for Nickel and Nickel Alloys

See abstract on p. 37.

Anodic Behaviour of Nickel

H. MEYER: 'On the Anodic Behaviour of Nickel.' *Doctorate Thesis presented to Die Technische Hochschule, Zürich*, 1952; 65 pp.

The literature is reviewed, and an account is given of experiments on the passivation of nickel anodes in sulphuric-acid electrolytes. Full details are given of testing apparatus and technique, and the mechanism of passivation is discussed.

Wear and Friction Properties of Nickel and High-Nickel Alloys

See abstract on p. 40.

ELECTRODEPOSITION AND OTHER COATING METHODS

Testing of Electrodeposited Coatings

P. A. CARTWRIGHT: 'A Survey of the Methods of Testing Electrodeposits.' *Engineering Inspection*, 1952, vol. 16, Summer, pp. 48-61; Autumn, pp. 100-5.

Part 1 reviews methods which have been proposed for testing adhesion, thickness, porosity, corrosion-resistance. Illustrations are shown of some of the apparatus used.

Part 2 deals with specific conditions of test for determining quality of individual types of coating. A useful table summarizes reagents used for chemical tests, conditions for chemical testing, and principal features of other forms of test applied for assessment of quality of coatings of cadmium, chromium, copper, gold, lead, nickel, silver, tin, zinc and Speculum.

A.S.T.M. Specifications for Nickel and Nickel Alloys

See abstract below.

NON-FERROUS ALLOYS

A.S.T.M. Specifications for Nickel and Nickel Alloys

AMER. SOC. TESTING MATERIALS: '1952 Book of A.S.T.M. Standards; Part 2, Non-Ferrous Metals.' Published by the Society, 1952; 1327 pp.

The 1952 edition of this triennial publication contains all Standards which have been formally adopted by the Society, together with A.S.T.M. Tentative Specifications, Methods of Test, and Definitions. The volume is one of a group of seven covering Standards for metallic and non-metallic materials. Sections of volume 2 which are of principal interest in relation to nickel-containing materials are: copper and copper alloys; non-ferrous metals and alloys; electrical-heating, resistance, and related alloys; electrodeposited metallic coatings.

Wear and Friction Properties of Nickel and High-Nickel Alloys

See abstract on p. 40.

Monel Stays in British Standard Locomotives

'Standard Class-4 2-6-0 Locomotives, British Railways.' *Engineering*, 1953, vol. 175, Jan. 2, pp. 12-13.

The article describes the main features of the seventh type of the twelve standard series of locomotives being built under the current construction programme of British Railways. (Reference is given to earlier descriptions of the first six standard classes.) The boiler design of the new class follows closely that of the London Midland Region Class-4 2-6-0 engine. Boiler shell plates are of ordinary quality steel, and, as in other locomotives built under this programme, all firebox water-space stays are of Monel, fitted with steel nuts inside the firebox. Longitudinal and transverse stays are of steel.

Nickel-Aluminium Bronze: Properties and Uses

'Nickel-Alloyed Bronze Provides Long Wear in Microscope Parts.' *Nickel Topics*, 1953, vol. 6, No. 1, p. 5.

This note describes the use, by Bausch and Lomb Optical Company, of nickel-aluminium bronze for the revolving, ball-bearing nose piece of microscopes. In the course of focusing, this part is subjected to considerable use and consequent wear, and the selection of nickel-aluminium bronze, as offering the properties required for such conditions, was made after a series of wear tests in comparison with other alloys. The nominal composition of the bronze used is given as copper 80·50, aluminium 10·50, nickel 4·75, iron 4·25, per cent. The nosepiece is cast to very close dimensions by a special method known as 'Aurora Vacuum Die Process'.

Attention is directed to the marked improvement in properties produced in aluminium bronzes by addition of nickel and iron. Typical mechanical properties of the alloy used for the microscope nosepiece are tabulated, and its wear- and fatigue-resisting qualities are emphasized. Further characteristics which are useful in various applications are its resistance to corrosion, and the fact that it provides a good base for chromium plating. A photograph illustrates some other typical uses of alloys of similar composition.

Nickel-Manganese Alloys

N. N. KURNAKOV and M. Y. TRONEVA: 'The Manganese-Nickel System.' *Brit. Abstracts, B.I.*, 1952, Oct., p. 1427; from *Comptes Rendus, Acad. Sci., U.R.S.S.*, 1949, vol. 68, pp. 73-6.

'Two arrests are observed in the cooling curves of systems containing up to 3·3 at. per cent. of nickel, and one only for alloys containing 3·62-11·8 at. per cent. nickel: these correspond with the transitions $\delta \rightarrow \gamma$ and $\gamma \rightarrow \beta$Mn. The transition temperatures of $\delta \rightarrow \gamma$ rise and those of $\gamma \rightarrow \beta$ fall, with rising nickel content. The phase transformations $\gamma \rightarrow \beta$, $\beta \rightarrow \gamma + \varepsilon$, and $\beta \rightarrow \varepsilon$ are observed in alloys containing 45·95-52·24 at. per cent. of nickel, and $\gamma \rightarrow \gamma + \varepsilon$ in alloys containing 53·35-62·74 at. per cent. of nickel. The transformations are also shown on the curves relating conductivity, temperature coefficient of conductivity, and coefficient of expansion with composition.'

Nickel-Chromium-Palladium Alloys

V. A. NEMILOW, T. A. VIDUSOVA and V. K. NIKITINA: 'Investigation of Alloys of the Palladium-Nickel-Chromium System.' *Izvest. Sekt. Platiny*, 1948, vol. 22, pp. 175-86; *Metallurgical Abstracts*, 1952, vol. 20, Dec., pp. 244-5.

The alloys studied were within the following range: palladium 10-95, chromium 1·25-78·75, nickel 1·25-78·75. They were subjected to thermal analysis and

microstructural examination, and determinations were made of Brinell hardness, and electrical resistance and its temperature coefficient. A summary of the main conclusions drawn is given in the abstract, *loc. cit.*

Magnetic Characteristics of Nickel-Cobalt Alloys

M. YAMAMOTO: 'Ferromagnetic Behaviour of Nickel-Cobalt Alloys.' *Science Reports, Research Inst., Tôhoku Univ.*, Ser. A, 1952, vol. 4, pp. 14-27.

Using the ballistic method, the authors determined magnetization curves at room temperature as a function of composition, on some 60 alloys covering the whole binary range. Measurements were also made of magnetization for various constant fields, saturation magnetization and field, magnetocrystalline anisotropy constant, and initial and maximum magnetic susceptibilities. From the data obtained, it is concluded that at room temperature the extent of the two-phase range in the nickel-cobalt system is wider than has previously been supposed, stretching from about 68 to about 78 per cent. cobalt.

Equipment for Thermal Treatment of Metals and Alloys

See abstract on p. 36.

NICKEL-IRON ALLOYS

Permanent Magnets: Review of Development and Current Position

W. DANNÖHL: 'Development and Present Position of Permanent-Magnet Materials.' *Stahl und Eisen*, 1953, vol. 73, Jan. 15, pp. 65-80; disc., pp. 80-1.

This is a very comprehensive review, supported by a *bibliography* of over 100 items. The author draws attention to the spectacular developments which have occurred in this field, particularly during the past 30 years, and he traces such development, from the point of view of materials used, and properties obtained, over the period 1900 to date. The essential characteristics of magnet materials are summarized in sections covering (1) martensitic steels, (2) α alloys, (3) alloys showing superstructure, (4) γ alloys, (5) α/γ alloys, (6) influence of mechanical working on permanent-magnet materials, (7) alloys in which preferred orientation is produced by heat-treatment in a magnetic field, (8) cast alloys solidified under conditions giving directional properties, (9) oxide magnets, (10) pressed and sintered powder-produced magnets, (11) magnets made from powders of ultrafine particle size. The next section of the review discusses the basic principles on which development of the various types of magnet material has been based, giving reference to the individual series in which the respective principles have been applied.

A detailed review is then made of the grades of permanent-magnet material in use in Germany. Notes on composition and properties are given, and comparison is made with materials currently employed for this purpose in other Continental countries, and in the U.K. and U.S.A. Reference is also directed to some unusual applications of certain of the more recently developed magnet alloys.

The final section of the review is theoretical in character, discussing the current state of knowledge on coercive force and the magnetization curve, and the nature of the modifications introduced by controlled precipitation in complex iron-nickel-aluminium-(cobalt)-base alloys.

Some suggestions are made as to potentially fruitful lines of research on coercivity, the demagnetization curve, and other aspects of the subject. The need for such fundamental research is strongly urged.

Magnetostriction of Single Crystals of Nickel Ferrite

R. M. BOZORTH and J. G. WALKER: 'Magnetostriction of Single Crystals of Cobalt and Nickel Ferrites.' *Physical Rev.*, 1952, vol. 88, Dec. 1, p. 1209.

Longitudinal and transverse magnetostrictive changes for cobalt and nickel ferrites, as a function of applied field strength, are graphically shown, and attention is directed to the unusually large magnetostrictive contraction observed in the (100) direction in a crystal of cobalt ferrite having the approximate composition corresponding to $Co_{0.8}Fe_{2.1}O_4$.

The crystals of nickel ferrite examined were of the $Ni_{0.7}Fe_{2.2}O_4$ type.

CAST IRON

Ni-Hard Equipment for Handling Sand and Gravel

'Ni-Hard Takes Severe Punishment in Log Washer Parts.' *Nickel Topics*, 1953, vol. 6, No. 1, p. 7.

Log washers are used at sand and gravel plants, to wash out clay, silt and other undesirable substances from sand and gravel aggregates. The work of separating the materials is performed principally by corrugated metal paddles, which are subject to abrasive wear in breaking down clays and sticky conglomerates, and conveying the separated gravel to the discharge end of the machine as the clay is washed over by the rising column of water. Use of Ni-Hard for the paddles has been found to minimize replacements, and to effect substantial economy in operating costs.

Ni-Hard Service in the Brick-Making Industry

'Brick Industry Finds Ni-Hard Castings Valuable. *Nickel Topics*, 1952, vol. 5, No. 8, pp. 1, 3.

This note reports the experience of the works of A. L. Schultz and Son Company, of Chicago, which for the past sixty years has been a large-scale manufacturer of machinery for brick-making. Progress in the output of such machines, e.g., from production of some 5,000 bricks per hour to the present rates of 35,000-40,000 per hour, has necessarily led to demand for improved materials of construction. The life of many items of equipment has been much

lengthened by the adoption, for parts subject to abrasive wear, of Ni-Hard, in place of the white cast iron formerly used. Service records, on which this article is based, show that the use of Ni-Hard permits longer productive periods, and eliminates shutdowns for replacement of parts (with attendant high labour costs). Although the initial cost of the Ni-Hard iron is slightly higher than that of white iron, overall service has proved its use to be highly economical. Typical items of brick-making equipment for which the alloy cast iron is successfully used include rolls used for removing stone from the clay; screw case liners and screws forming part of extruding machinery, and extrusion dies. These applications are described and illustrated. In all of them the records indicate not less than a 3:1 ratio in favour of the service obtained from Ni-Hard, by comparison with white cast iron.

Current Developments in S.G Iron

W. W. BRAIDWOOD: 'The Progress of Spheroidal-Graphite Iron.' Paper to Conference of Italian Foundrymen, Oct., 1952; *Foundry Trade Jnl.* 1953, vol. 94, Feb. 26, pp. 231-6.

The development of S.G. iron to date is briefly reviewed, and particular reference is made to methods of overcoming subversive elements, and the use of magnesium as the addition metal. Some mechanical and physical properties of S.G. iron are discussed, and outstanding applications are described. S.G. iron is now in production on a substantial and constantly expanding scale, by methods which are being continually improved.

Wear and Friction Properties of Nickel and High-Nickel Alloys

See abstract on p. 40.

CONSTRUCTIONAL STEELS

Thermal Stabilization of Austenite in Nickel-Alloy Steels

H. M. OTTE and T. KO: 'Thermal Stabilization of Austenite in Carburizing Steels.' *Jnl. Iron and Steel Inst.*, 1953, vol. 173, Jan., pp. 31-5.

When austenite of a given chemical composition is cooled to a fixed reference temperature below M_S, at a rate sufficiently fast to give martensitic structures, the degree of transformation frequently depends on rate of quenching. The amount of retained austenite increases with decreasing rate of cooling. It has recently been shown that in iron-carbon-nickel alloys containing about 1 per cent. of carbon the difference is due to an effect occurring during quenching in the range 300°-400°C., which lowers the M_S and reduces the amount of martensite formed at a given reference temperature. It was also observed that the amount of martensite formed below M_S is affected by isothermal holding above and below M_S. These effects are known as thermal stabilization of austenite.

Isothermal stabilization of austenite has previously been observed in high-chromium, high-carbon steels above M_S, and also in other steels below M_S. It has been shown that stabilization, being an activated process, is slow at temperatures below 200°C. in nickel steels, and that stabilization below this temperature contributes little towards the increase in retained austenite during normal quenching. Isothermal stabilization at room temperature may, however, be important if the steel is to be treated at sub-zero temperatures for removal of retained austenite, since the time of holding before sub-zero quenching may be long, and rate of stabilization is much increased in the presence of martensite. The effect is more significant in alloy steels, in which considerable amounts of austenite may be present at room temperature, and it has been found that the rate of stabilization may be high in the presence of chromium, and probably also of other carbide-forming elements.

In the work described in the present paper the effects of stabilization during quenching, on the amount of retained austenite, were studied in two steels, of the compositions shown below:—

	'Krupp' Steel %	Nickel Steel %
Carbon	0·12	0·18
Nickel	3·80	4·89
Chromium	1·24	0·32
Molybdenum ..	0·07	0·29
Manganese	0·40	0·41
Silicon	0·22	0·21
Sulphur	0·018	0·013
Phosphorus	0·017	0·014

The effects of variation in carbon content, on the behaviour of both steels, were also investigated.

The results of the experiments show that isothermal stabilization can take place in Krupp steel at room temperature, at least with carbon contents above 0·9 per cent. The effect of stabilization occurring, for example, after holding for 22 hours at room temperature, could be removed by further quenching to −79°C. There is some indication that the rate of lowering of M_S with increasing carbon content is greater in the Krupp steel than in plain carbon steels.

With regard to the influence of carbon on the amount of austenite retained in the nickel steel at room temperature, it was observed that above 1 per cent. of carbon carbide precipitation occurred during air cooling, causing increased transformation of austenite. In the low-carbon region air-cooled specimens retained more austenite than those which had been water-quenched. These results are compared with those obtained on homogeneous specimens of the same steel produced by carburizing $\frac{3}{16}$-in. sections for various periods and subsequently homogenizing in charcoal at various temperatures between 900° and

1100°C. It would appear that at a given carbon level, more austenite is retained in the carburized steel than in the comparable homogeneous one. Investigation of the effect of austenitizing temperature on retained austenite, using homogeneous specimens, gave no indication that the amount of retained austenite in these nickel steels was affected by temperature within the austenite range.

Influence of Boron Additions on Low-Alloy Nickel-containing Steels

H. KRAINER and M. KRONEIS: 'Boron Additions to Constructional Alloy Steels.' *Stahl und Eisen*, 1952, vol. 72, Dec. 18, pp. 1652-7.

The authors report tests of the influence of boron on (*a*) three through-hardening steels: a manganese-silicon type (average composition carbon 0·33, silicon 1·15, manganese 1·20, per cent.) and two low-alloy nickel-chromium-molybdenum grades, and (*b*) a lean-alloy nickel-chromium case-hardening steel. Hardening characteristics, structure, and mechanical properties were determined.

The observations made confirm the beneficial effects of small amounts of boron, which have the effect of delaying the onset of transformation without greatly influencing its final stage. It is concluded that in heat-treatable steels of which the hardenability characteristics are not entirely adequate, and in which it is not desired to increase the chromium, manganese or molybdenum content, boron is the obvious addition, but that its potentially beneficial influence will not be realized unless a sufficiently high hardening temperature is used. The authors consider that in Germany no substantial conservation of nickel can usefully be obtained by use of boron, since nickel has already been eliminated from steels in which it was used to improve mass hardenability. Tests on the case-hardening steel appeared to indicate that addition of boron exerts no appreciable effect.

Nickel-containing Materials in Naval Gas Turbines

See abstract on p. 43.

HEAT- AND CORROSION-RESISTING ALLOYS

Wear and Friction Properties of Nickel and High-Nickel Alloys

R. L. JOHNSON, M. A. SWIKERT and E. E. BISSON: 'Wear and Sliding Friction Properties of Nickel Alloys Suited for Cages of High-Temperature Rolling-Contact Bearings.
Part I. Alloys Retaining Mechanical Properties to 600°F.' *Nat. Advisory Committee for Aeronautics, Tech. Note* 2758, Aug., 1952; 30 pp.

Cages (separators or retainers) have been a principal source of failure in the rolling-contact bearings of aircraft gas turbines. Investigation has shown that it is generally a case of lubrication failure, and that the trouble occurs at the cage locating surfaces. Factors influencing such failures are discussed in an earlier report (*N.A.C.A. Tech. Note 2384* : see abstract in *Nickel Bulletin*, 1952, vol. 25, No. 1, pp. 10-11). The combined effect of all the conditions operating is the occurrence of extreme boundary lubrication and metallic adhesion, which lead to the ultimate deterioration of mating surfaces. Current design, which tends towards higher operating temperatures, higher surface speeds, and use of less viscous lubricants, is likely to increase the severity of the cage problem, for rolling-contact bearings.

One possible solution, the feasibility of which is being exhaustively studied at the Lewis Flight Propulsion Laboratory at Cleveland, is to make the cages of improved bearing materials, i.e., of materials which have inherent 'anti-weld' characteristics under marginal conditions of lubrication. Brass and bronze, which are currently used, are likely to prove unsuitable for operation at temperatures of 400° - 600°F. (205°-315°C.), and at such temperatures it is also possible that the spheroidal-graphite iron which was favourably reported on in the earlier paper may also prove inadequate. A study is therefore being made of the friction and wear characteristics of a range of other materials, among them some which have not until now been considered as bearing alloys. Properties required for this type of service, at elevated temperatures, are strength, corrosion-resistance, and anti-weld properties.

The tests reported in this Note were made, not as simulating cage-operating conditions, but as a means of obtaining fundamental, comparative information on friction and wear properties, which are a general measure of adhesion. Due to lack of high-temperature equipment, the tests were made at room temperature, such conditions being considered satisfactory since it is generally true that materials showing good friction properties at room temperature will also be satisfactory in this respect at elevated temperatures, provided that their mechanical strength is sufficiently high. The tests were made with loaded hemispherically-shaped specimens of the various nickel-containing materials, sliding in a continuous path on rotating 52100 steel disc specimens. Most of the experiments were run at a sliding velocity of 5,000 feet per minute, with loads of 50-1593 grams. Wear debris was studied by means of X-ray diffraction techniques.

The materials subjected to test were: cast Monel, cast modified H Monel, cast S Monel, Invar, Ni-Resist, and L nickel. Data already obtained on wrought Monel and on Nichrome V were compared with results obtained on the other materials.

The conclusions drawn are summarized below:—

Desirable operating characteristics of all the materials studied could be associated with the development, on the rider surface, of a naturally formed film which X-ray diffraction patterns indicated was predominantly nickel oxide. High-temperature operation in air would accelerate formation of the beneficial surface film; in consequence, the best of these materials could perform well in cages of high-temperature

	Ni %	Cu %	Fe %	Mn %	Si %	C %	Cr %
L Nickel (annealed) ..	99·4	0·1	0·15	0·2	0·05	0·02 max.	—
Monel (wrought)	67·0	30·0	1·4	1·0	—	—	—
Monel (cent. cast)	67·0	29·0	3·0	1·50	—	—	—
Modified H Monel	62·06-62·8	31·43-32·3	1·49-1·95	0·53-0·76	3·25-3·66	0·016-0·025	—
S Monel (cast)	63	30	2	—	4	—	—
Invar (h.r.)	36	—	64	—	—	—	—
Ni-Resist (type 3)	28·91	—	62·5	—	1·76	2·58	3·47
Nichrome V (wrought) ..	80	—	—	—	—	—	20

rolling-contact bearings. Pre-treatment, for formation of a surface film before operation, would probably be beneficial.

On the basis of wear and friction properties, Ni-Resist, modified H Monel, and Invar were the best of the materials studied in this investigation, although they did not perform so well as the S.G. iron previously tested. Ni-Resist showed the best film-forming properties. Ni-Resist and the H Monel alloy have thermal coefficients of expansion approaching that of steel. The cast modified H Monel showed inconsistent performance, arising from erratic formation of the surface film: this had previously been noted as characteristic of Monel. In general, cast Monel alloys have better friction and wear properties than the wrought forms of the corresponding alloys. Annealed L nickel gave good performance at light loads, but had insufficient yield strength for operation with the heavy loads.

Part II. 'Alloys Retaining Mechanical Properties above 600°F.' *Nat. Advisory Committee for Aeronautics, Tech. Note* 2759, Aug., 1952; 29 pp.

The testing technique used in this section of the investigation was similar to that described in Part I, *see* preceding abstract. The nickel-containing materials studied in Part II were: cast beryllium-nickel, heat-treated beryllium-nickel, cast Inconel, Nimonic 80, Inconel X, Refractalloy 26, and Discaloy. L nickel was compared as a standard.

In this set of experiments also it was found that desirable operating properties observed in the materials studied were associated with development, on the rider surface, of a naturally formed dark film consisting predominantly of nickel oxide.

In most of the experiments, cast Inconel proved to be the best material. It was not subject to surface failure even under the most severe conditions imposed, and it showed desirably low wear characteristics. This material also has good mechanical properties at high temperatures, and a coefficient of thermal expansion which approaches that of steels. Such properties make cast Inconel appear attractive for cages of rolling-contact bearings.

Under all conditions of operation, Nimonic 80 was also one of the better materials. Due to the fact that its thermal expansion coefficient is greater than that characteristic of steels, this alloy may, it is suggested, be best suited for inner-race riding cages of rolling-contact bearings. Both cast Inconel and Nimonic 80 have wear properties comparable to, and friction properties lower than, those of the S.G. irons referred to in earlier reports.

Beryllium-nickel, Refractalloy 26, and Discaloy all showed signs of incipient failure at some stage during the wear runs.

	Ni %	Cr %	Fe %	Co %	Mo %	Ti %	Al %	Si %	C %
Inconel (cast)	77·75	13·5	6·0	—	—	—	—	2·0	—
Inconel X (wrought) ..	73·0	15·0	7·0	—	—	2·5	—	—	—
Nimonic 80 (wrought) ..	74·2	21·2	—	—	—	2·4	0·6	0·05	0·04
Refractalloy 26 (wrought)	37	18	18	20	3	2·8	0·2	—	0·5
Discaloy (wrought) ..	25	13	55	—	3	1·8	0·6	0·5	0·05
Beryllium-Nickel (cast)	96·0	0·66	Be 2·66-3·0		—	—	—	—	0·50 max.
Beryllium-Nickel (solution-annealed and heat-treated) ..	96·0	0·66	2·66-3·0		—	—	—	—	0·5 max.

Oxidation of Metals and Alloys

O. KUBASCHEWSKI and B. E. HOPKINS: 'Oxidation of Metals and Alloys.' Published by Butterworths Scientific Publications, London, 1953; 239 pp. Price 35/-.

In the field of corrosion, phenomena associated with metal-liquid reactions have until now claimed the major share of attention in research and the literature. Various relatively recent developments in high-temperature and chemical engineering have, however, combined to arouse an active interest in metal-gas reactions, particularly in the oxidation of metals at elevated temperatures. Information on this subject has already built up into a relatively large literature, a fact which is demonstrated by the 549 references embodied in the text of this book. Publication has, however, been in widely scattered sources, and no systematic correlation has previously been made. In summing up and critically taking stock of the data available, theories advanced, and opinions held, the authors have therefore made a valuable contribution to present knowledge and future progress.

The main object of the book is 'to give an appraisal of the state of research on the oxidation of metals and alloys.' It is shown that in the period following the classic work of Tammann in the 1920's, attention has been increasingly directed to the laws governing surface oxidation of metals. The development of theories of oxidation is historically traced, the points at which existing theories are inadequate are indicated, and attention is directed to some major experimental results which still await theoretical explanation. The general arrangement of the subject matter is briefly shown below:—

Chapter 1 discusses factors which require to be taken into account when dealing with the mechanism of oxidation. It includes tables of relevant thermodynamic and thermal data for the compounds which can form on the surface of metals.

Chapter 2 deals with the experimental side of the investigation of oxidation reactions. Techniques which have been used for examination of oxidation layers on metals, and methods which have been developed for determining the thickness of oxide layers or the rate of oxidation reactions, are considered, mainly from the point of view of the principles involved, precautions which should be taken in using them, and the relative merits of the different techniques.

Chapter 3 is concerned with the special theories concerning parabolic and logarithmic oxidation, internal oxidation, the formation of several oxide layers, and the oxidation of binary alloys.

Chapter 4 comprises a collection of experimental results relating to the rate of oxidation of individual metals, and the effects of addition of alloying elements. The probable mechanism of oxidation of the respective materials is discussed.

The material contained in the book is restricted to oxidation of metals and alloys at temperatures of about 100°C. and above. Results obtained at room temperature are in some cases included as a support to observations made at higher temperatures, and in connexion with their demonstration of principles closely related to high-temperature oxidation. The term 'oxidation' is used throughout in the general sense of any surface process which is accompanied by a delivery of electrons to the metal: it thus includes surface reactions leading to the formation of metal compounds such as oxides, hydroxides, nitrides, sulphides, sulphates, etc. Corrosion in aqueous solutions is *not* included in the review.

The Nimonic Series of Alloys: Research and Development

'Developing the Nimonic Alloys.' *Aeroplane*, 1952, vol. 84, Jan. 23, pp. 122-4.

In September, 1946 this journal published an account of research in the laboratories of The Mond Nickel Company, Limited, and associated development by Messrs. Henry Wiggin & Company, Limited, which led up to the introduction of Nimonic 75, and Nimonic 80, the first members of this group of high-temperature alloys. The present article deals with methods which are used in development of alloys giving still better properties, suitable for use at progressively higher service temperatures. The description of technique and equipment used for determining creep strength and other properties is prefaced by a note on the various types of alloy now available in the Nimonic series. A graph indicates the comparative strength, at high temperatures, of Nimonic 80, 80A, 90 and 95, on the basis of values for stress-for-rupture in 100 hours.

Reference is also made to difficulties which have had to be overcome in production, due to the inherent toughness of the alloys, which introduces special problems in fabrication. Notes are added on some of the machines and methods used, in the Wiggin plant, for rolling, pressing, and other operations.

Drilling Alloys of the Nimonic Series

'Drilling Nimonic: Production Figures obtained in Machining Three of the Series.' *Aircraft Production*, 1953, vol. 15, Feb., p. 38.

Nickel-chromium-base alloys of the Nimonic series, which have been developed with the specific aim of giving toughness and strength at high temperatures, are inevitably more difficult to machine than some of the less refractory materials. Practical experience in production conditions has, however, proved that with suitable tools and machining techniques satisfactory results can be obtained. The tables below show details of output which may be secured under normal conditions. The figures in Table I relate to drilling of Nimonic 80, using Herbert Auto Junior and capstan machines. The drills used were 0·9375 in. diameter, and were of standard type. The length of cut was 0·650 in.

It is to be noted that, in contrast to the speed of 112 r.p.m. given in the table, an ordinary 18 per cent. tungsten-steel twist drill cannot normally be operated at a speed higher than 65 r.p.m.

Table II relates to drilling of turbine blading in three alloys of the Nimonic series: 80, 80A and 90. In this

case a slow automatic feed was used. The drills employed are made with two flutes, slow spiral, and have an angle of 14½ degrees. The 13/32-in. drill has a ¼-in. flute, standard point-angle, and a web slightly thicker than usual. The 33/64-in. drill is similar, but has a flute width of $\frac{5}{16}$-in. The tools used were of a steel containing tungsten 20-22, cobalt 6-7, per cent., with molybdenum, chromium, and vanadium, which is used for heavy-duty conditions involving fast speeds and heavy feeds.

Table I

	Auto Junior	Capstan
Speed, r.p.m.	112	103
Feed, rev. per in. . .	240	209
Feed, in. per rev. . .	0·0042	0·0048
Feet per min.	28	26
Cutting Time . .	1·45 min.	1·31 min.
Average number of components between grinds	50-60	60-70

Table II

Drill sizes 13/32 in. and 33/64 in. Speed, r.p.m. 229

	Test A Nimonic 80 and 80A	Test B Nimonic 90
Average number of holes per grind	100	70
Depth of holes . .	¾ in.	1 in.
Cutting time	4 min.	3½ min.

Nickel-containing Materials in Naval Gas Turbines

'G. 2 Naval Gas Turbine.' *Engineer*, 1952, vol. 195, Jan. 9, pp. 58-9.

This article describes the gas turbine designed by Metropolitan-Vickers Electrical Company, Ltd., for installation in the motor torpedo boats 'Bold Pathfinder' and 'Bold Pioneer' both of which are undergoing sea trials. The 'G.2' engines (modified 'Beryl' type) are designed on the same cycle as the Gatric engine which was employed in the M.T.B. 2009, but are larger and give improved performance. The turbines will be used for high-speed running: for cruising Diesel engines are provided. Design and operation are described and illustrated.

Moving blades in the gas turbine are of Nimonic 80A, and fixed blades of Nimonic 80. Austenitic nickel-chromium steels have been employed for the annular combustion chamber and combustion chamber fixing rings, the power turbine rotor (which is made from three separate forgings welded together), and the moving blades of the power turbine and the turbine casing. The gear and pinion of the reduction gears are of constructional nickel-alloy steels, as is the turbine end-shaft of the compressor.

Tests on Materials for Steam Superheaters

F. G. ELY and F. EBERLE: 'Experimental Superheater for Steam at 2000 p.s.i. and 1250°F. Progress Report of Field Operation.' *Trans. Amer. Soc. Mechanical Engineers*, 1952, vol. 74, July, pp. 803-12.

Issued under the aegis of the Joint A.S.T.M.-A.S.M.E. Committee on Effect of Temperature on Properties of Metals.

In order to investigate the properties of new high-strength materials potentially suitable for high-temperature steam superheaters, a test element constructed of 2-in. o.d. tubes was installed in an operating boiler unit at which steam pressure of 2000 p.s.i. was available from existing boilers. The element was designed to receive steam at 950°-1000°F. (510°-540°C.), from the superheater outlet of these units, and to increase its temperature to 1200° or 1250°F. (650° or 675°C.), under conditions in which the test element should function exactly as would be expected of a commercial unit, having complete exposure of the tubes to the action of flue gases from pulverized-coal firing, to normal heat-transfer rates, and to three-dimensional stresses, thus corresponding to realistic operation. The tubes were also subject to the internal action of highly superheated steam at established rates of mass flow.

Tubing of the following materials was thus exposed: Croloy 2¼ (chromium 2·45, molybdenum 0·99, per cent.); Types 304, 347, 321, 316 and 318 nickel-chromium austenitic steels; Timken 16-25-6 (chromium 16·18, nickel 26·42, molybdenum 6·40, per cent.), and Armco 17-14 Cu-Mo (chromium 15·50, nickel 13·48, copper 3·15, molybdenum 2·18, per cent.). Details are given of welding rods used for the respective materials.

To date of the report the unit had been in service for 5000 operating hours, of which approximately one-third had been with steam-outlet temperatures above 1200°F. (650°C.), one-third in the range 1100°-1200°F. (595°-650°C.), and the remainder at temperatures below 1100°F. (595°C.).

Since all the materials and the welds were found, on removal after the first period, to be in satisfactory condition, the repaired test element was again (in March 1951) placed in similar service. The tests will be continued indefinitely, and at a later stage comparison will be made between the condition of the tubes which have been under test with materials of the same types retained at the time of fabrication.

Although the initial experience to date does not warrant the drawing of definite conclusions, the evidence so far obtained gives favourable indication of the possibility of constructing, on an economic basis, commercial steam superheaters for operation in the range of 2000 p.s.i. and 1200°F. (650°C.) final temperature.

Resistance of Superheater Materials to Corrosion by Combustion Gases

H. A. BLANK, A. M. HALL and J. H. JACKSON: 'Behaviour of Superheater Tubing Materials in Contact with Combustion Atmospheres at 1350°F.'
Trans. Amer. Soc. Mechanical Engineers, 1952, vol. 74, July, pp. 813-19.

This paper is also sponsored by the Joint A.S.T.M.-A.S.M.E. Committee on Effect of Temperature on the Properties of Metals. The full programme of the research, part of which is reported in this publication, is concerned (1) with the reaction of high-pressure, high-temperature steam with commercially available materials considered potentially suitable for use in this application, and (2) with corrosion of flue gases and slag-forming ash. Part 2 is being carried out in two sections, covering (*a*) evaluation, under field conditions, of various materials, with regard to resistance to corrosion by the combustion products of the various fuels used for boilers, and (*b*) laboratory investigation of the effect of certain components of combustion atmospheres, on resistance of the materials to attack. The present paper relates only to the field-test section of Part 2, in which specimens were exposed in ten different plants.

Fourteen commercial materials were selected for test, covering austenitic stainless steels of eleven different types, nickel-base alloys (Inconel and Illium G), and aluminized mild steel. A description is given of arrangements made for installation of the specimens in the gas streams: where possible they were placed in positions in which they would attain an average temperature of 1350°F. (735°C.). Details are given of test racks, specimens, types of units at the respective stations, fuel burned, temperatures, etc.

The results are shown in terms of loss of weight and corrosion penetration; they are discussed in relation to variations in operating conditions at the respective plants, fluctuations of temperature, etc. A considerable amount of detailed data is given.

The general conclusions drawn are:—

(1) There are wide differences in general corrosiveness among the atmospheres produced by the combustion of the various kinds of fuel used for steam-generating units. In the tests reported in this paper, low-sulphur coal and gas produce combustion products which are only mildly corrosive. High-sulphur, high-alkali, and high-vanadium fuels, on the other hand, produce combustion products which are often extremely corrosive. The general degree of corrosiveness appears to be related to the sulphur, vanadium, and alkali-metal content of the fuel.

(2) Excluding considerations of strength and resistance to internal corrosion, it may be said that under mild corrosion conditions a variety of materials is available for superheater tubing to operate at metal temperatures up to 1350°F. (735°C.) without appreciable external attack. Under very corrosive conditions all the materials tested were corroded. Among them, however, A.I.S.I. 309, 310 and 314 (see table below) usually showed best resistance to both general corrosion and subsurface attack.

See also—

C. J. SLUNDER, A. M. HALL and J. H. JACKSON: 'Laboratory Investigation of Superheater Tubing Materials in Contact with Synthetic Combustion Atmospheres at 1350°F.' *Amer. Soc. Mechanical Engineers, Paper* 52-A-36, Nov.-Dec., 1952; 11 pp.

This report supplements the one referred to in the previous abstract. The object of the tests made was two-fold: (1) to delimit, more closely than was possible in field-test conditions, the influence of the individual variables in the combustion atmospheres to which the test materials were subjected, and (2) to correlate results of field and laboratory experiments. The atmospheric variables of main interest investigated were: high and low levels of sulphur dioxide, carbon monoxide, and alkaline constituents. The basis synthetic combustion gas used in the laboratory experiments was chosen to simulate the flue gas obtained when a fuel containing carbon:hydrogen in an 85:15 ratio is burned with 20 per cent. excess air. The materials exposed were identical with those used in the field tests. Eight 1000-hour tests were made, in conditions covering various combinations of the three atmospheric variables. Details are given of methods adopted to ensure the presence of 'alkali' components in the atmosphere, to simulate the effects produced by alkali metals in the fuel. This is a particularly complex problem, due to the many components which have been found in external deposits on boiler tubes, and to the lack of knowledge on the mechanism of their formation. In these tests the specimens were immersed in an alkali salt mixture of suitable composition, and subsequently exposed in the furnace with the other gaseous components.

At completion of the tests the specimens were cooled in a nitrogen atmosphere, removed from the furnace, and descaled by the sodium-hydride process. Evaluation of behaviour was on the basis of both metal loss from scaling, and the extent of subsurface attack.

The results indicate that the conditions selected for these tests were not sufficiently severe to cause

A.I.S.I. Type	C %	Ni %	Cr %	Mn %	Mo %	Other Elements %
309	0·13	14·54	23·12	2·0	0·15	—
310	0·08	20·3	25·2	1·7	0·02	—
314	0·09	21·45	24·56	1·3	0·13	Si 2·20

excessive scaling, and any differences observed between the various materials tested, under any of the conditions described, were of a minor order of magnitude.

From the standpoint of metal loss only, Inconel showed the least attack: it was followed closely by a group consisting of A.I.S.I. 310, 314, 309 and 309S. Only four of the materials, A.I.S.I. 316, 321, 17-14 chromium-nickel steel containing copper and molybdenum, and Timken 16-25-6 chromium-nickel-molybdenum steel, lost more than 0·001 in. per year from surface corrosion.

Extent of penetration by subsurface attack was determined by metallographic examination of cross sections of the specimens. On many of the materials it was found that this form of attack penetrated to a considerably greater depth than scaling. The best combination of low metal loss and minimum subsurface attack was shown by the 25 chromium-12 nickel and the 25 chromium-20 nickel types. On the basis of total depth of metal affected, the 18-8 chromium-nickel steel of Type 321 was also among the best of the specimens, but this observation was not borne out by the field tests, due, it is believed, to the more severe conditions in the latter series. The 16-25-6 chromium-nickel-molybdenum steel and the austenitic steels of 321, 347, 308 and 316 types showed the greatest degree of subsurface attack. Inconel also appears to be subject to this form of deterioration.

With the exceptions mentioned above, the laboratory test results checked well, in a general way, with those of the field tests, particularly with regard to behaviour in units burning natural gas and low-sulphur fuel. Conditions resulting from burning high-sulphur, high-vanadium fuel were not included in the laboratory experiments.

Statistical evaluation of the metal-loss results indicated that the increase in corrosion caused by increasing the sulphur dioxide in the atmosphere from 0·02 to 0·20 per cent. was significant. No significance could be attached to the minor differences caused by variation in carbon monoxide content up to 0·1 per cent. by volume, nor to the differences obtained by partial immersion of the specimens in an alkali-metal/salt mixture during the tests. It is concluded that the mechanism of corrosion resulting from the presence of alkali metals in the fuels is complex, and requires further study.

Comparison of High-Alloy Welding Electrodes of Varying Nickel Content

J. P. KIENBERGER: 'Experiments on the Properties and Uses of Heat-Resisting Ferritic-Austenitic Arc-Welding Electrodes.' *Sheet Metal Industries*, 1953, vol. 30, Jan., pp. 23-43.

This very detailed report is a translation, from Radex Rundschau, of a doctorate thesis presented to the Technische Hochschule, Braunschweig, in 1944. The basis material welded was a steel containing carbon 0·23, silicon 0·79, manganese 0·65, chromium 23·5, nickel 2·98, per cent. Arc welds were made with lime-fluorspar-coated electrodes having core wires of steel of the following types: straight-chromium (ferritic); high-chromium, low-nickel (ferritic-austenitic), and high-alloy nickel-chromium (fully austenitic). The suitability of the respective electrodes was assessed by means of hardness, tensile, and bend tests on the welds: general observation of the operating characteristics of the electrodes: scaling tests on the welded joints, and microscopical and X-ray examination.

The comparison was made with the aim of determining:—

(1) whether a nickel content, in the wire, of the same percentage as that in the parent metal, ensures the qualities required in the welded joint;
(2) whether nickel in the electrode wire can be partly or entirely replaced by manganese;
(3) whether addition of nitrogen makes it possible to dispense with the austenite-forming elements nickel and manganese;
(4) whether, by the simultaneous use of manganese and nitrogen in the electrode wire, it is possible partially or entirely to replace nickel.

Detailed conclusions on the influence of the respective elements are drawn from the large amount of experimental data presented. Core wires of the following composition are recommended as giving, on steel of the type studied, welds having good resistance to scaling:—carbon 0·1 max., silicon 0·8-1·0, manganese 3·0, chromium 22-24, nickel 1·5, nitrogen 0·25, per cent.

Nickel-base High-Temperature Coating Alloy

'A Coating Alloy for High-Temperature Use.' *Engineer*, 1953, vol. 195, Feb. 20, p. 274.

The note describes the properties and uses of a facing alloy developed by Rolls-Royce, Ltd., for coating of valves in civil aircraft engines. It is claimed that the use of such coating on the valve head and seating has increased the period between scheduled valve overhauls to 1000 hours, and that even after that time only a small proportion of the treated valves require to be withdrawn from service. The alloy used, known as C.26, is of nickel base, and contains chromium, aluminium, molybdenum, and other minor additions. Although hard, it is not brittle under the repeated impact involved in service, and does not crack radially under the time-temperature stresses imposed in high-power engines. It is used on inlet valves, due to its resistance to the action of the products of combustion of leaded fuels. The good wearing characteristics of C.26 result in very low loss of tappet clearance, thus lessening maintenance costs. It is claimed that the alloy resists oxidation at all temperatures up to 1250°C., and that, provided the iron content is below 1 per cent., it is highly resistant to lead oxide and lead oxybromide up to 800°C., the maximum temperature at which it is safe to run highly stressed valves for long periods. C.26 is also resistant to corrosion by molten caustic soda, and has been used, in the form of cast containers, for fluxes containing fluoride. The coating is deposited by means of oxy-acetylene torch: a flux may be used if preferred, but no intermixing of coating and base metal must occur. Where the iron content is not critical the arc-welding process may be used. Casting of C.26 alloy by normal commercial methods

presents no difficulties, and it is machinable without undue difficulty. Typical physical and mechanical properties are tabulated in this note. Manufacturing and marketing rights are held by Deloro Stellite, Ltd., Birmingham.

Nickel-containing Materials for Use in High-Temperature Water Systems

C. R. BREDEN *et al.*: 'Water Corrosion of Structural Materials.' *U.S. Atomic Energy Commission Publn. ANL* 4519, 1951; 197 pp.

A summary is given of tests on various materials considered suitable for use in high-temperature water systems. The types examined included stainless steels, other alloy steels, plain carbon steels, cobalt and nickel-base alloys, copper and copper alloys, chromium-plated materials, hardfaced steels, and some ceramics. Full details are given of experimental procedure used in the tests, including the design of suitable high-pressure autoclaves. Austenitic stainless steels, of both general and precipitation-hardening types, and alloys of high cobalt content, were found to be the most suitable materials for parts in contact with oxygenated water at 500°F. (260°C.).

Influence of Processing on Niobium-Stabilized Austenitic Steel

T. V. SIMPKINSON: 'Behaviour of Carbides in Niobium-Stabilized Austenitic Stainless Steel.' *Metallurgia*, 1953, vol. 47, Jan., pp. 18-24.

The author presents a detailed study of the influence of temperature of final hot working, heat-treatment, and welding, on the distribution of precipitated carbides in niobium-stabilized chromium-nickel steel within the specification range covering A.I.S.I. 347 (carbon 0·08 max., chromium 17·0-19·0, nickel 9·00-12·00, niobium 10 times the carbon content). The nature of the eutectic carbide present in these steels (essentially a solid solution of NbC and NbN, with approximately equal contents of carbon and nitrogen) is discussed, and the reaction of this eutectic to various thermal conditions is demonstrated. In addition to the eutectic carbide, there are present in niobium-stabilized steels carbides which precipitate, in a high state of dispersion, after completion of solidification, when the casting is initially cooling, or after subsequent re-heatings. Typical examples of these 'dot' carbides are shown and discussed, and their significance, in relation to the resistance of the steel to intercrystalline corrosion, is discussed. The final section of the paper reports observations made with regard to the nature of the grain-boundary precipitates developed (*a*) near 2400°F. (1315°C.); (*b*) in the range 850°-1650°F. (455°-900°C.); (*c*) in the zone adjoining a weld.

On the basis of the results recorded, the author emphasizes that niobium-stabilized steels should not be regarded as 'fool-proof', since incorrect processing procedure can result in grain-boundary carbide precipitation which may (under some conditions) make the steel susceptible to intergranular corrosion. Experience has shown that the deficiencies of improperly processed material may become apparent only under relatively severe conditions of service.

Accelerated Corrosion Test for Sheet Steel

A. J. OPINSKY, R. F. THOMSON and A. L. BOEGEHOLD: 'The General Motors Research Corrosion Test: A Cyclic Humidity Accelerated Corrosion Test for Sheet Steel.' *A.S.T.M. Bull.*, 1953, No. 187, Jan., pp. 47-51.

The paper describes a test developed (by General Motors Corporation) to simulate the worst conditions of automotive exposure, such as those occurring in sheltered areas where the steel remains wet for long periods of time. The variables which have been accentuated in the test have, as far as possible, been held within limits which could occur in service: temperature 125°F. (52°C.), a slow humidity cycle, and the use as dip of a dilute electrolyte of sodium and calcium chloride, to resemble salt-filled slush generated on city streets during the winter. A small amount of sulphuric acid is added to the dip solution to allow for the presence of sulphur compounds in the atmosphere. Such conditions are found to secure formation, after an initial period, of an almost non-protective rust closely similar to that appearing on sheet steel exposed in service under the conditions described. There is evidence that the results of this test rate several steels in about the same order of merit as atmospheric-exposure testing: comparisons are made with exposure tests at Bayonne, N.J. and at Kure Beach. The magnitude of corrosion loss in steels so tested is about three times that of the same steels under a modified A.S.T.M. salt-spray test (salt concentration 5 per cent. by weight) for the same length of time. The present paper gives full details of test apparatus and procedure, and shows some results on typical sheet steels, among them 5 per cent. nickel steels.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks*.

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